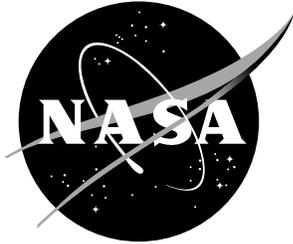


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Inviscid Flow Computations of the Shuttle Orbiter for Mach 10 and 15 and Angle of Attack 40 to 60 Degrees

Ramadas K. Prabhu

Lockheed Martin Engineering & Sciences Company, Hampton, Virginia

December 2001

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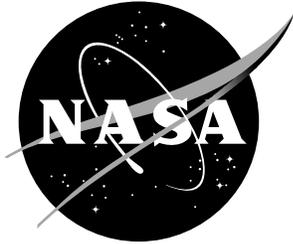
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Summary

This report documents the results of a computational study done to compute the inviscid longitudinal aerodynamic characteristics of the Space Shuttle Orbiter for Mach numbers 10 and 15 at angles of attack of 40, 50, 55, and 60 degrees. These computations were done to provide limited aerodynamic data in support of the Orbiter contingency abort task. The Orbiter had all the control surfaces in the undeflected position. The unstructured grid software FELISA with the equilibrium air option was used for these computations. Normal force, axial force, and pitching moment coefficients were computed. The hinge moment coefficients of the bodyflap and the inboard and outboard elevons were also computed. These results were compared with data from Operational Aerodynamic Data Book (OADB) and those computed using the software GASP. The comparison with the GASP results showed excellent agreement in C_m and C_A , and also in the flap and elevon hinge moment coefficients at all the points. The present axial force coefficients were smaller than those computed by GASP. Similar agreement was notice with the elevon and bodyflap hinge moments. There were noticeable differences between the present results and those from the OADB at angles of attack greater than 50 degrees.

Software

The present computations were done using the unstructured grid inviscid flow software FELISA. This software consists of unstructured surface triangulator, volume grid generator, and flow solvers. The flow solver can be run with any of the options including the perfect gas, equilibrium gases (air and Mars gas), and Mars real gas. More information about FELISA may be found in [1]. FELISA software has been successfully used for inviscid hypersonic flow computations, (See for example [2], [3], [4], and [5].) The present computations were done using the hypersonic flow solver with the equilibrium air option.

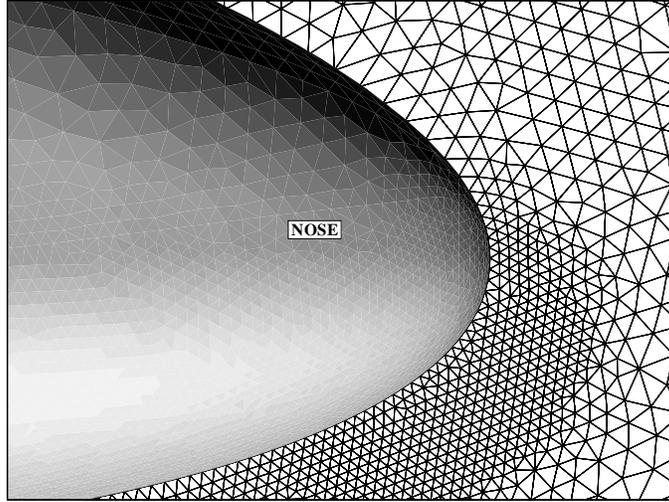
Grids

Two separate grids were used in these computations. The two grids had the same spacing distributions every where except near the nose of the Orbiter. Around the nose, the minimum spacing was 2 inches in the coarse grid, whereas it was reduced to 0.2 inches in the fine grid. This led to better capturing of the flow features near the nose of the Orbiter. A view of the two grids on the symmetry plane near the Orbiter nose is shown in Fig. 1 The information on these grids is given here:

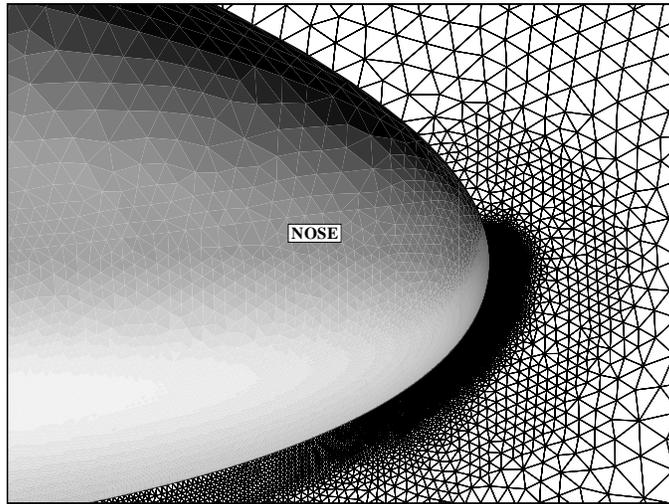
	Fine Grid	Coarse Grid
No. of Surface Points	91,895	64,365
No. of Surface Triangles	183,786	128,726
No. of Tetrahedral Elements	10,950,214	7,979,561
No. of Nodes	1,855,685	1,350,843

Freestream Conditions

The freestream conditions for the two Mach number cases used in the present computations are as follows:



(a) Coarse Grid



(b) Fine Grid

Figure 1: Comparison of the surface triangulations near the nose.

Mach Number	10.0	15.0
Velocity	10,552 ft/s (3217.2 m/s)	15,679.05 ft/s (4779.0 m/s)
Temperature	463.7 °R (257.6 K)	454.7 °R (252.6 K)
Density	5.28E-6 slugs/ft ³ (2.7213E-3 kg/m ³)	7.77E-6 slugs/ft ³ (4.0047E-3 kg/m ³)

The computed normal and axial forces, the pitching moment, the bodyflap hinge moment, and the elevon hinge moments were non-dimensionalized in the conventional way. The reference quantities used for this purpose are as follows:

Coefficients	C_N, C_A, C_m	Flap H.M.	Elevon H.M.
Reference Area (in ²)	387,360	19,440	30,240
Reference Length (in)	474.72	81.0	90.7

The pitching moment reference point is located on the symmetry plane, 841.7 in. behind the nose and 38.5 in. above the longitudinal axis. The longitudinal axis passes through the nose of the Orbiter.

The hinge moment of the bodyflap was computed about the hinge line located at a distance of 1296 in. from the nose and 51 inches below the the longitudinal axis. This hinge line is perpendicular to the symmetry plane.

The hinge moment of the elevon was computed in a similar manner The elevon hinge line is located at a distance of 1151 in. from nose. The hinge line meets the symmetry plane at 76.652 in. below the longitudinal axis, and makes a dihedral angle of 5.229 deg.

Results

The computations were done on the NAS Origin 2000 parallel computers using 64 processors. The results are listed in Table 1. Similar computations had been done by Papadopoulos, P.E. et al, ([6]) assuming 5-species nonequilibrium air. Present results and the GASP results are shown plotted in Figures 2 - 8 along with the corresponding data from OADB. See [7]. It should be noted that the OADB and GASP results are for Mach 15.

Refining the grid near the Orbiter nose did not make any noticeable differences in the results at Mach 10. The differences in the results obtained using the coarse and the fine grids were less than 1%. The contribution of the nose to the aerodynamic coefficients is predicted adequately by the coarse grid. The fine grid, however, allowed better capturing of the sonic line on the symmetry plane (See Figure 5.)

Figures 4 indicates that the present values of C_A are lower than both OADB data and the GASP results. This is the result of absence of skin friction in the present computations. At high Mach numbers and particularly at high angles of attack, the normal force is primarily due to the pressures on the windside of the vehicle. Inviscid flow computations adequately predict the flow over the windside surfaces. The OADB C_m and C_A values deviate from the FELISA computations as well as the GASP results at angles of attack greater than 50 degrees.

Hinge moments of the bodyflap, and the inboard and the outboard elevons were computed, and are listed in Table 2. Results are shown plotted in Figure 6 - 8. Also shown plotted in these figures are the hinge moment coefficients from OADB and those computed using the GASP software.

<i>MachNo.</i>	<i>AngleofAttack</i> (<i>degree</i>)	C_A	C_N	C_m	<i>Grid</i>
15.0	40.0	1.1666E+00	5.2610E-02	-2.1479E-02	Coarse
15.0	50.0	1.6219E+00	5.3694E-02	-6.1119E-02	Coarse
15.0	55.0	1.8389E+00	5.2696E-02	-8.6418E-02	Coarse
15.0	60.0	2.0361E+00	5.0532E-02	-1.1205E-01	Coarse
10.0	40.0	1.2100E+00	5.1487E-02	-3.8619E-02	Coarse
10.0	50.0	1.6598E+00	5.2579E-02	-7.9042E-02	Coarse
10.0	60.0	2.0509E+00	5.0837E-02	-1.1930E-01	Coarse
10.0	40.0	1.2103E+00	5.1676E-02	-3.8489E-02	Fine
10.0	50.0	1.6601E+00	5.2720E-02	-7.8926E-02	Fine
10.0	60.0	2.0509E+00	5.1016E-02	-1.1926E-01	Fine

Table 1: Inviscid aerodynamic data for Mach 10 and 15.

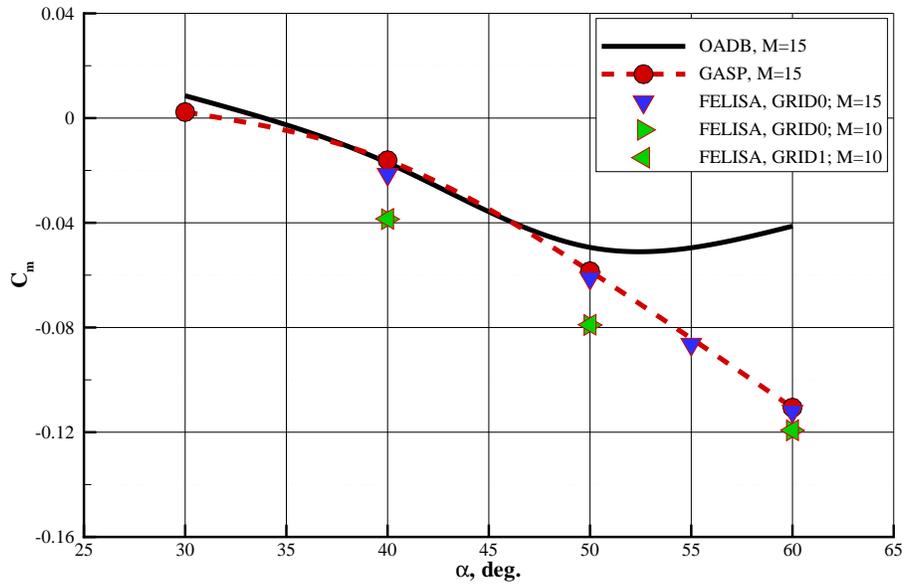


Figure 2: Pitching moment coefficient

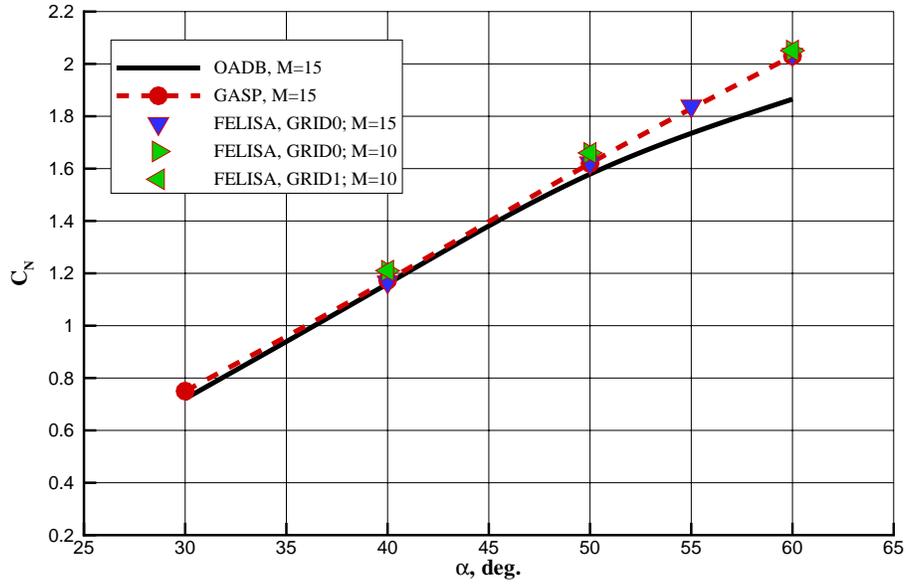


Figure 3: Normal force coefficient

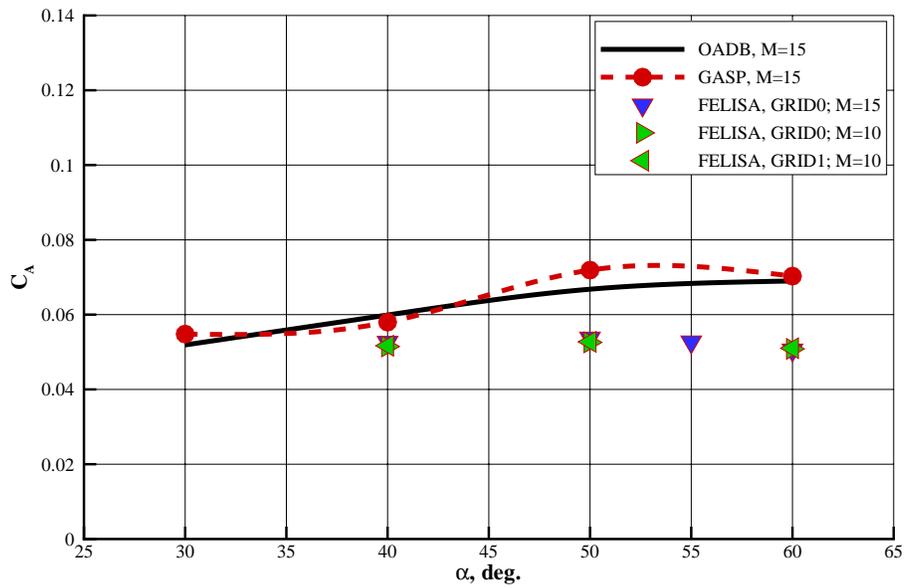


Figure 4: Axial force coefficient

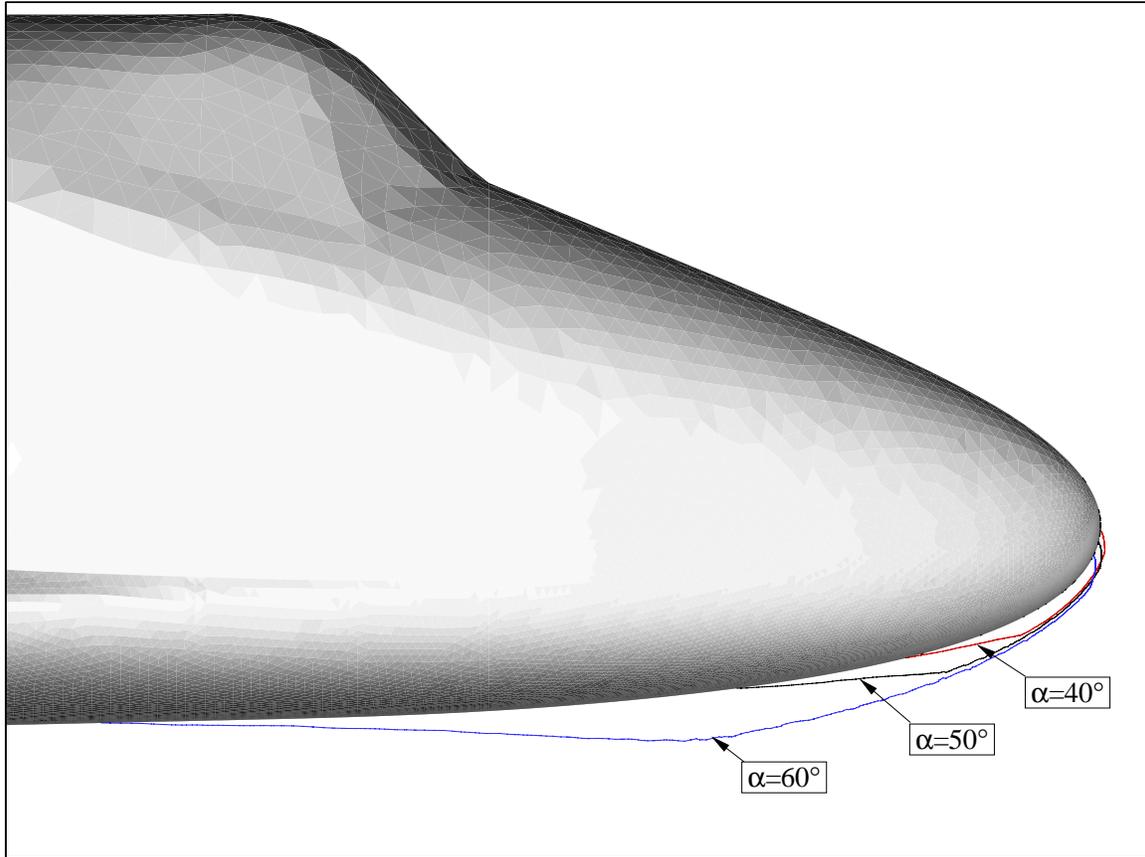


Figure 5: Symmetry plane sonic lines (fine grid); Mach 10, $\alpha=40$, 50, and 60 deg.

The OADB hinge moment coefficients curves have an inflexion point at about an angle of attack of 45 degrees. However, the computed data do not exhibit this trend. It may be observed that the FELISA results agree very well with the GASP results. The computed inboard elevon hinge moment coefficients agree with the OADB data up to an angle of attack of 60 degrees. The maximum difference is about 0.025 at $\alpha = 50$ degrees. The outboard elevon hinge moment coefficients agree with the OADB data only up to an angle of attack of 50 degrees. At angles of attacks greater than 50 degrees, the outboard elevon hinge moment coefficients continue to increase negatively, whereas the OADB data tend to level off. At $\alpha = 60$ degrees the difference between the computed and OADB data is 0.25. The computed bodyflap hinge moment coefficients agree with the OADB data except at an angle of attack of 60 degrees where the difference between the two is 0.05.

<i>Mach</i> No.	<i>Angle of Attack</i> (<i>degree</i>)	<i>Flap</i> HM	<i>Eleven</i> HM (<i>Inboard</i>)	<i>Eleven</i> HM (<i>Outboard</i>)	<i>Grid</i>
15.0	40.0	-2.7225E-01	-1.4658E-01	-7.3060E-02	Coarse
15.0	50.0	-4.2318E-01	-2.2984E-01	-1.0923E-01	Coarse
15.0	55.0	-5.0862E-01	-2.7592E-01	-1.2916E-01	Coarse
15.0	60.0	-5.9762E-01	-3.2156E-01	-1.4806E-01	Coarse
10.0	40.0	-2.9027E-01	-1.6308E-01	-8.1999E-02	Fine
10.0	50.0	-4.4477E-01	-2.5192E-01	-1.2019E-01	Fine
10.0	60.0	-6.0888E-01	-3.3267E-01	-1.5078E-01	Fine

Table 2: Flap and eleveon hinge moment coefficients for Mach 10 and 15.

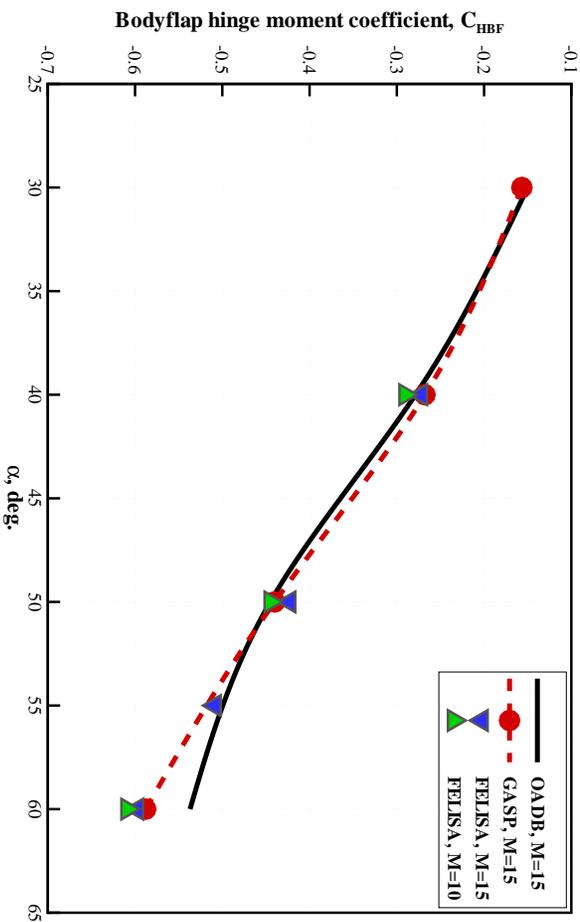


Figure 6: Bodyflap hinge moment coefficients

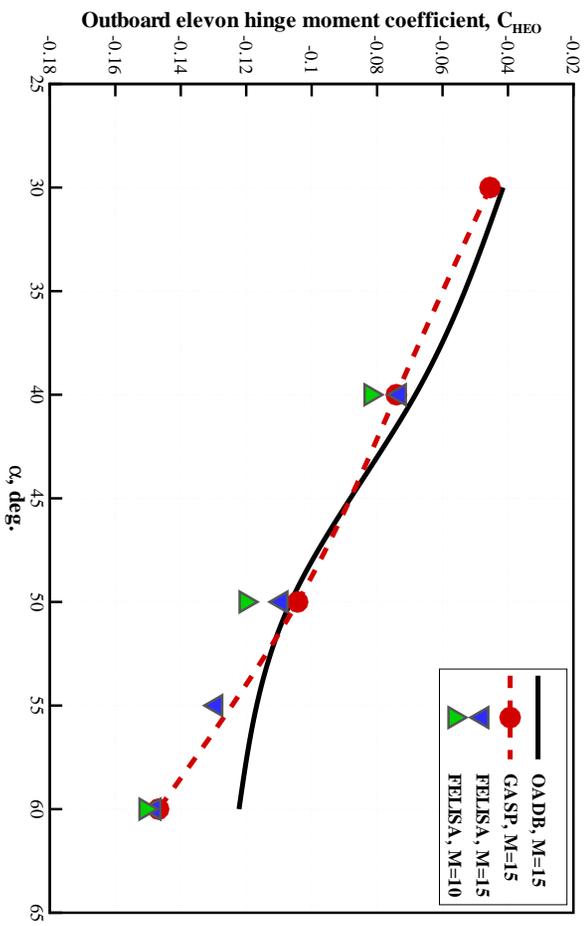


Figure 7: Outboard elevon hinge moment coefficients

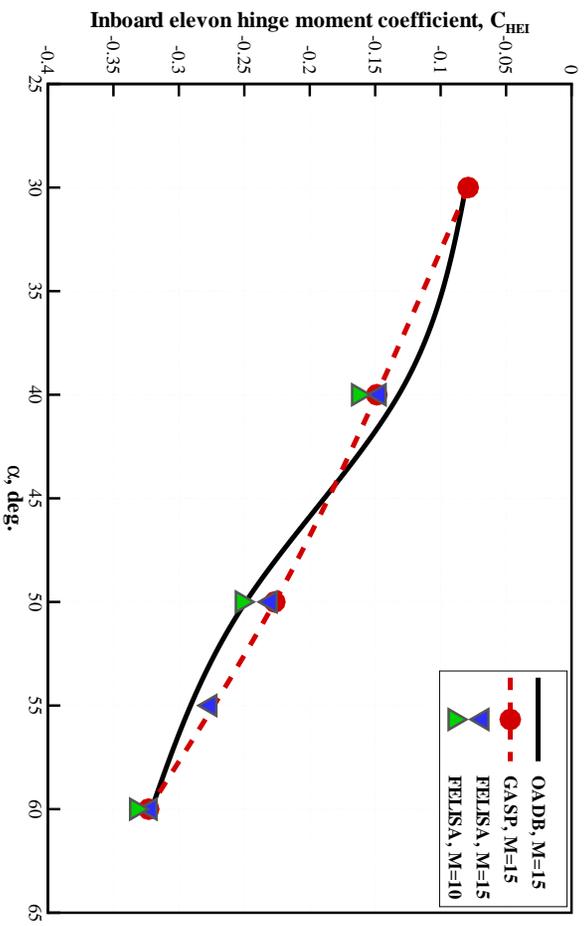


Figure 8: Inboard elevon hinge moment coefficients

References

- [1] Peiro, J., Peraire, J., and Morgan, K., “FELISA System Reference Manual and User’s Guide,” Tech. Report, University College of Swansea, Swansea, U.K., 1993.
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- [3] Prabhu, R.K., “An Inviscid Computational Study of an X-33 Configuration at Hypersonic Speeds,” NASA CR-1999-209366, July 1999.
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- [5] Prabhu, R.K., “Summary Report of the Orbital X-34 Wing Static Aeroelastic Study,” NASA Contractor Report 210850, April 2001.
- [6] Papadopoulos, P.E. et al, “CFD Simulations in Support of Shuttle Orbiter Contingency Abort Aerodynamic Database Enhancement,” AIAA 2001-3067, 35th AIAA Thermophysics Conference, June, 2001.
- [7] “Operational Aerodynamic Data Book,” Boeing, Human Space Flight and Exploration, Huntington Beach, CA, Boeing Document STS85-0118 CHG 9, 2000.

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